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PRINCIPLES OF CLASSIFICATION AND CORRELATION OF THE PRE-CAMBRIAN ROCKS¹

I

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A half-hour summary of the principles of classification and correlation of the pre-Cambrian rocks can give no more than the barest outline of the subject.

In the classification and correlation of the pre-Cambrian formations we lack the guide of fossils. While life existed in pre-Cambrian times, and a few fossils are found in several areas, they are not sufficiently abundant to serve either for the purposes of classification or correlation. How far-reaching this handicap is will be realized when this paper is contrasted with those that follow. In considering the questions of classification and correlation of the later formations, fossils occupy a paramount position. It is true that the faunal breaks are often and probably are generally dependent upon physical causes, and the latter are frequently considered; but when the determinations are made, the fauna rather than the physical factors are given first place.

In the classification and correlation of the pre-Cambrian our sole criteria are physical. Therefore we have for the discriminations only those guides which for the fossiliferous rocks are commonly regarded as subordinate. It follows that with the pre-Cambrian rocks we are on less certain ground than with the later formations. However,

¹ Read before Section E of the American Association for the Advancement of Science, December, 1908.

the very fact that fossils are not available in studying the pre-Cambrian has led the workers in this field to a careful consideration of the physical criteria and their relative value.

Among the physical factors which have been used in the classification and correlation of the pre-Cambrian, the following are the more important: (1) Lithological character; (2) Continuity of formations; (3) Likeness of formations; (4) Like sequence of formations; (5) Subaerial or subaqueous deposits; (6) Unconformities; (7) Relations to series of known age; (8) Relations with intrusive rocks; (9) Amount of deformation; (10) Degree of metamorphism.

1. *Lithological character*.—The first step in the study of rocks from a physical point of view is to determine the character of the formations, series, and groups—whether igneous or sedimentary; if igneous, whether plutonic or volcanic, acid or basic; if sedimentary, whether psephite, psammite, pelite, limestone. While according to definition a formation is essentially a lithological unit, usually this unit is more or less composite, consisting of many somewhat variable beds and often of several members of different character. Because of the variability of the elements constituting a formation, there are an indefinite number of permutations and combinations of these factors. This results in giving a given formation, series, or group special peculiarities which often enable one to recognize it even when actual connections of the various outcrops have not been observed.

Accepting any of the current theories as to the history of the earth, the rocks of the earliest time are dominantly of igneous origin, and those of later time dominantly sedimentary. Since the earliest Cambrian rocks contain remains of all the great types of life, it is certain that antecedent to this time the more fundamental and greater part of organic evolution took place. Hence in a full pre-Cambrian succession we should expect the rocks of the early pre-Cambrian to be dominantly igneous and those of the later pre-Cambrian to be dominantly sedimentary. In accordance with the natural expectation, in practically all of the great regions of the world in which the pre-Cambrian have very extensive exposures, and in which close studies have been made, we find that the basal series of rocks is dominantly igneous, and the superior series dominantly sedimentary.

2. *Continuity of formations.*—Where formations in different districts are found to be continuous, they are supposed to be of the same age. It is realized that this conclusion is not absolute, for in the case of a great slanting transgression of the sea, the basal clastic deposits of the early part of the transgression may be considerably earlier than those in the later part, although the formations may be continuous. However, as yet given pre-Cambrian formations have not been traced to sufficiently great distances to introduce important errors upon this account.

3. *Likeness of formations.*—Where in different districts there are like formations, this is of assistance in correlation. Thus, if in several districts of a geological province but a single limestone formation is observed in any one, and the limestone of the different districts has the same peculiarities, there is a natural tendency to suppose all the limestone to be part of a single formation. However, the criterion of lithological likeness alone is not sufficient to establish identity. This is illustrated by the three iron-bearing formations of the Lake Superior region. Because these formations were of such an exceptional and peculiar character, and were so remarkably alike, it was supposed for a long time that they were of the same age. For a number of years this mistaken belief was a serious hindrance to an understanding of the succession and structure in this region. The weakness of lithological likeness in correlation is due to the fact that the same set of physical conditions has frequently occurred during geological time, and thus formations practically identical even in the combinations of their variations, including color, banding, nature of beds, etc., have been produced again and again.

4. *Like sequence of formations.*—Similar sets of formations in the same order furnish a criterion for correlation, of much greater consequence than the likeness of a single formation. But even this criterion has severe limitations, for similar sets of formations in the same order may have been deposited a number of times during a geological era; for instance, when a sea transgresses over a land area there are normally formed in order a psephite, a psammite, a pelite, and a non-clastic formation, and frequently over this, another pelite. Several such similar sets of formations are known in the pre-Cambrian in a single geological province.

5. *Subaerial or subaqueous deposits*.—Closely connected with the third and fourth criteria is the question as to whether the deposits were laid down under air or under water. It is clear that the conditions of deposition of these two classes of rocks are so different and the nature of the formations which may be contemporaneous so variable, that there is great difficulty in correlating the two. Also it is plain that the difficulties in correlating disconnected continental deposits are scarcely less great. Only recently has serious study been undertaken to discriminate subaerial and subaqueous deposits. This subject will not be gone into here, since it is one which has been recently discussed in several extended papers. I may, however, speak of one point. So far as we can yet determine the subaerial deposits are in general not so well assorted nor so likely to be sharply separated into distinct formations as the subaqueous deposits. This statement is believed to hold although it appears that under exceptionally favorable conditions the aerial deposits may be pure quartzose sands. Consequently cleanly assorted quartzose sands, pure limestones, and series composed of sharply contrasted formations are regarded as strongly favoring the idea of subaqueous deposition. As yet there is no evidence that air has the discriminating capacity which water has in producing cleanly assorted sands. If it is difficult to discriminate subaerial or subaqueous deposits, it is much more difficult to discriminate subaqueous deposits of the inland lakes and seas from those of the ocean.

6. *Unconformities*.—Unconformities are of great assistance in classification and correlation. It has been intimated that the great physical movements producing unconformities are frequently the real causes of faunal changes. Irving was the first fully to realize the importance of unconformities in correlation. The criteria by which unconformities are determined and their magnitude and significance analyzed cannot be discussed in a short paper. Those interested in this aspect of the subject must be referred to the original discussions.¹

It should be remarked, however, that unconformities may have

¹ Roland Duer Irving, "On the Classification of the Early Cambrian and Pre-Cambrian Formations," *Seventh Annual Report*, U. S. G. S., pp. 365-454; Charles Richard Van Hise, "Principles of North American Pre-Cambrian Geology," *Sixteenth Annual Report*, U. S. G. S., pp. 724-34.

a very variable extent and significance. It is now realized that a sharp orogenic movement may take place resulting in uplift, erosion, subsidence, and therefore discordance of strata, which may not affect an adjacent area. Thus it should clearly be understood that it cannot be assumed that unconformities due to orogenic movements are more than of district extent. There are, however, great movements of uplift and subsidence which are continental and may be even inter-continental. Unconformities due to movements of this kind may have a very wide extent, and may thus be used for correlation from province to province, or possibly even from continent to continent. But in order that this may be fully done, it is necessary to show that the unconformity upon which correlation is based is an extensive one.

As yet insufficient careful study has been made of known unconformities from this point of view. Here is a great and fundamental field for investigation. If the known unconformities of the world were broadly studied, it is probable that many can be determined to be local, others to be provincial, others continental, and a few inter-continental. No more important determination than this remains to be made in geology. So far as I can see until this work is done there will be no very close correlation of pre-Cambrian formations from province to province and from continent to continent.

7. *Relations to series of known age.*—The relations of a formation, series, or group, to other formations, series, and groups of known age are of very great assistance in correlation. Frequently a formation, series, or group may be continuous or recognizable in the different districts of a geological province when other formations, series, or groups are not continuous. The position of the latter with relation to the former, whether above or below, and if above or below, conformable or unconformable, are valuable helps in correlation. Thus the Keweenaw is practically continuous about the entire Lake Superior basin. This is the only series of which this is true. The position of the series called Upper Huronian immediately but unconformably below the Keweenaw in different districts in connection with other facts is of great significance.

8. *Relations with intrusive rocks.*—The older is a series the more intricately is it likely to be cut by intrusive rocks, and this relation is of assistance in correlation in connection with other criteria. If a

series is intricately cut by igneous rocks, all of which stop at a definite horizon, this is strong evidence that the adjacent rocks free from such intrusives are later and probably belong to a different series.

9. *Amount of deformation.*—The amount and nature of the deformation are of assistance in correlation within limited areas. Upon the whole, the older a series the greater and more intricate the deformation. The difference in the amount of deformation in the pre-Cambrian series wherever there is a somewhat full succession of formations is sufficiently great to make this an important factor in the classification and correlation of the formation.

10. *Degree of metamorphism.*—The amount of metamorphism is a factor in correlation. Upon the whole, the older a series the more likely it is to be metamorphosed, but this criterion has severe limitations, since within comparatively short distances the closeness of folding and the quantity of intrusives may greatly vary, and these are very important factors in metamorphism. The worker among the pre-Cambrian rocks must have a very thorough understanding of the principles of metamorphism and the nature of the transformations through which rocks go. For, in working out the stratigraphy of the pre-Cambrian, if the criterion of the original character is to be used, it is necessary to know the rocks which the now greatly metamorphosed varieties represent.

GENERAL STATEMENT

In actually working out the succession of formations, series, and groups in the different districts of a geological province and in correlating them, all of the above criteria must be used. It is in judgment in appreciating the value of each of these criteria and their combinations that the skill of the pre-Cambrian stratigraphical geologist appears.

To this time, from my point of view, the only divisions of the pre-Cambrian which have been proved to be general, if not world-wide, are those of the Archean and the Algonkian. This subject I shall not take up in detail, since I have recently discussed it in another address.¹

¹ Charles Richard Van Hise, "The Problems of the Pre-Cambrian," *Bulletin, Geological Society of America*, Vol. XIX, pp. 1-28.

However, it may be said in summary that the Archean is a group dominantly composed of igneous rocks largely volcanic and for extensive areas submarine. Sediments are subordinate. The Algonkian is a series of rocks which is mainly sedimentary. Volcanic rocks are subordinate. The Algonkian sediments where not too greatly metamorphosed are similar in all essential respects to those which occur in the Paleozoic and later periods. When the Algonkian rocks were laid down essentially the present conditions prevailed on the earth. The Archean rocks on the other hand indicate that during this era the dominant agencies were igneous. The physical conditions had not yet become such as to lead widely to the orderly succession of sedimentary rocks like those being formed today. On the whole the deformation and metamorphism of the Archean are much farther advanced than the Algonkian. The two groups are commonly separated by an unconformity which at many localities is of a kind indicating that the physical break is of the first order of importance. As evidence of this, at many places are the fundamental difference in the character of the rocks, the greater intricacy of intrusion, greater deformation and metamorphism of the older group, and deep intervening erosion. In some localities a part of these phenomena are lacking, but the significance of an unconformity is determined by the places where evidences of its magnitude occur rather than where lacking. So profound are the contrasts between the Archean and the Algonkian in each of the great regions of the world in which the pre-Cambrian has been studied, and so similar are each of these great groups with reference to the fundamental principles discussed that it has been regarded as safe to correlate these two groups even when in distant geological provinces. In making this correlation it is not supposed that the formations of one province are of exactly the same age as those of another province, but that the formations assigned to the Archean and Algonkian respectively in any given case belong to the two great eras of the pre-Cambrian represented by the rocks of these groups.

For extensive areas the Archean may be divided into Laurentian and Keewatin. These divisions are purely lithological, the former being mainly plutonic acid igneous rocks and the latter basic igneous rocks, largely volcanic. The Algonkian in many of the various

geological provinces may be divided into two or more series separated by unconformities. The formations of these series are commonly sedimentary, although igneous rocks are often abundant. As a whole, to the Archean group ordinary stratigraphical methods do not apply. To the Algonkian such methods are as applicable as to the Paleozoic and later series.

While the subdivisions of the Archean and of the Algonkian can be frequently equated in the same geological province, as, for instance, in the case of the Upper Huronian in the different districts of the Lake Superior region, it has not been found practicable to equate them from province to province. That is to say, one cannot be certain as to the correspondence of individual Algonkian series of China, Scandinavia, and of the Cordilleran region. If, as above suggested, it becomes possible to work out the physical history of the continents so that it may be determined which of the unconformities are continental, and intercontinental, or if in the pre-Cambrian rocks distinctive faunas are found, then closer correlation of the pre-Cambrian in different geological provinces may be possible than the Archean and Algonkian. In the meantime we must be content with the classification of the pre-Cambrian rocks in different geological provinces into Archean and Algonkian, with the understanding that the formations placed in each of these groups belong in a general way to the two early eras of the earth, during the first of which the agencies were dominantly igneous, and during the second of which the conditions had become similar to those of today. Further, within each geological province the Archean and Algonkian may be divided into series and formations which for each province are given local names.